

Case 1: Bulb Tee Bridge

PROBLEM STATEMENT

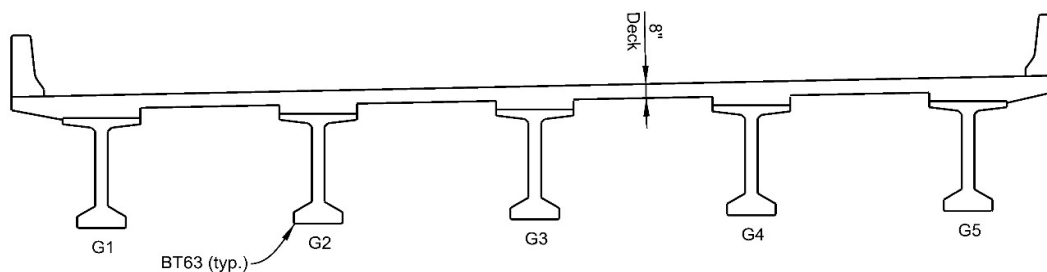
Case 1 illustrates how to set the haunch at supports for a BT girder bridge. Partial depth precast deck panels will be allowed, thus a minimum haunch thickness of 1 in. will be maintained at all locations. At supports, an additional 0.5 in. is provided for construction tolerance, giving a total min. haunch of 1.5 in. required at supports. See Section 5.5.2.1 of this BDM for more information.

The profile grade of the bridge is a crest vertical curve, with the bridge alignment on a horizontal curve with a constant cross-slope. The bridge is supported by chorded girders. The example shows how both the vertical and horizontal deck geometrics affect the deck profile above the girders, and thereby affect the haunch depths.

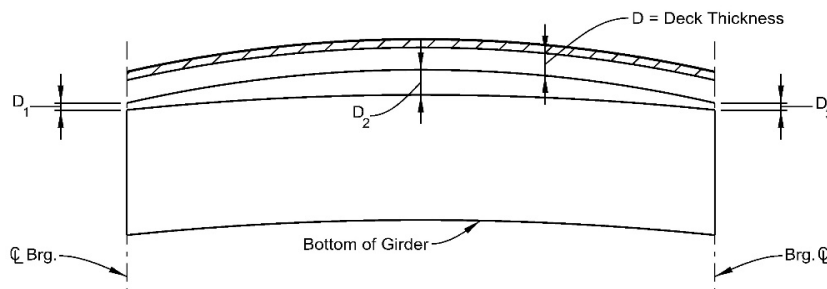
For this example, the design $f'c$ per BDM Section 5.3.1.2 was used for the given predicted girder cambers and DL deflections, not the optional actual values permitted in BDM Section 5.5.2.1.D.

The dead load deflections given in this example do not contain an increase for long-term effects, permissible per BDM Section 5.5.2.1.E of this BDM.

Positive values indicate upward camber or deflection.



Bridge Section View



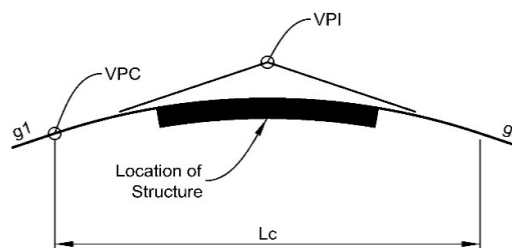
Girder Elevation View

GIVENS

Girder span length, L	100	ft.
Deck cross-slope, CS	0.06	ft./ft.
Proposed haunch at CL brg. at CL girder, $D_1 = D_3$	3.00	in.
Assumed weighted average haunch for DL, $D_{avg,DL}$	5.81	in. (may require iteration)
Girder top flange width, B_{tf}	43	in.
Dead load deflection, Δ_{DL}	-1.51	in. (includes superimposed DL)
Predicted girder camber at deck placement, C_{dp}	3.43	in. ($C_{dp} = P/S \text{ Camber} - \Delta_{Girder \text{ Self Weight}}$)

GIVENS (Continued):**Vertical Curve Data:**

Station at VPI =	5+00.00
Elevation at VPI =	5280
STA @ CL abut. 1, G1 =	4+50.00
STA @ CL abut. 2, G1 =	5+50.00
Curve length, L_c =	400 ft.
Grade in, g_1 =	8.0 %
Grade out, g_2 =	-8.0 %

**Horizontal Curve Data:**

Radius at G1 CL brg, $R = 1275$ ft. (may not be equal to radius of HCL)

CALCULATIONSStep 1: Profile effect due to vertical curve

$$ELEV_x = ELEV_{VPC} + g_1 * x + \left(\frac{r}{2}\right) * x^2$$

$$r = \frac{(g_2 - g_1)}{L_c} \quad (g \text{ in } \% \text{ and } L_c \text{ in STA})$$

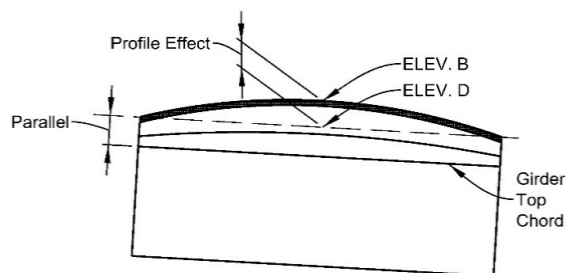
$$ELEV_{VPC} = ELEV_{VPI} - \frac{g_1}{100} * (STA_{VPI} - STA_{VPC})$$

$$STA_{VPC} = STA_{VPI} - \frac{L_c}{2}$$

$$r = -4.000 \text{ \%}/STA$$

$$STA_{VPC} = 3+00.00$$

$$ELEV_{VPC} = 5264.00$$



	X (STA)	$g_1 * x$	$r/2 * x^2$	ELEV	
CL Abut. 1	1.50	12.00	-4.50	5271.50	ELEV _A
Midspan	2.00	16.00	-8.00	5272.00	ELEV _B
CL Abut. 2	2.50	20.00	-12.50	5271.50	ELEV _C

$$\text{Profile effect 1, } \delta_{PE1} = (ELEV_B - ELEV_D) * 12 \frac{\text{in.}}{\text{ft.}}$$

$$ELEV_D = 0.5 * (ELEV_A + ELEV_C)$$

$$ELEV_D = 5271.50$$

$$\delta_{PE1} = 6.00 \text{ in.}$$

CALCULATIONS (Continued):Step 2: Profile effect due to chorded girders

$$\text{Profile effect 2, } \delta_{PE2} = -M * CS * 12 \frac{\text{in.}}{\text{ft.}}$$

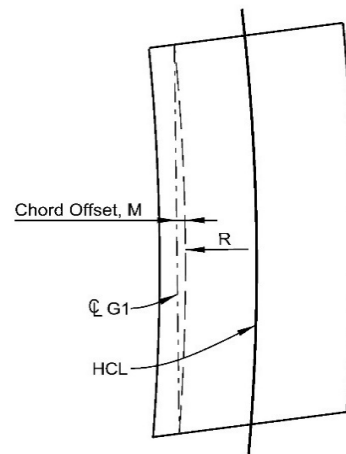
$$\text{Chord offset, } M = \frac{L}{2} * \tan \frac{\alpha}{4}$$

$$\text{Intersection angle of curve along chord, } \alpha = \frac{360 * L}{2\pi R}$$

$$\alpha = 4.49^\circ$$

$$M = 0.98 \text{ ft.}$$

$$\delta_{PE2} = -0.71 \text{ in.}$$

Step 3: Combined profile effect

$$\text{Profile effect, } \delta_{PE} = \delta_{PE1} + \delta_{PE2}$$

$$\delta_{PE} = 5.29 \text{ in.}$$

Step 4: Cross-slope effect

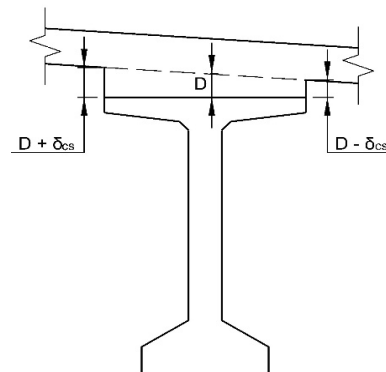
$$\text{Cross-slope effect, } \delta_{CS} = \frac{B_{tf} * CS}{2}$$

$$\delta_{CS} = 1.29 \text{ in. (+/-)}$$

Step 5: Check minimum estimated haunch at supports

$$\text{Estimated haunch, } D_{1,\min} = D_1 - \delta_{CS}$$

$$D_{1,\min} = 1.71 \text{ in.}$$



OK, $D_{1,\min} >$ minimum haunch thickness at supports of 1.50 in.

Step 6: Check estimated haunch at midspan

$$\text{Estimated haunch at midspan, } D_2 = \frac{D_1 + D_3}{2} - \Delta_{DL} - C_{dp} + \delta_{PE}$$

$$D_2 = 6.37 \text{ in. @ CL Girder}$$

Step 7: Verify assumed weighted average haunch for DL

$$\text{Actual average haunch for DL, } D_{\text{avg,DL}} = \frac{(D_1 + 10 * D_2 + D_3)}{12}$$

BDM Eq. 5-1

$$D_{\text{avg,DL}} = 5.81 \text{ in.}$$

OK, $D_{\text{avg,DL}}$ matches assumed average haunch used for dead loads

Note: D_2 may be used as the haunch thickness at midspan for the following items:

- Calculating Δ_{DL} reported on the girder sheet and used in setting deck elevations
- Calculating haunch concrete quantities

CALCULATIONS (Continued):**Step 8: Calculate camber tolerances per BDM 5.5.2.1.D**

$$\text{Over-camber tolerance, } \delta_{\text{over}} = 0.20 * C_{\text{dp}} \geq +1.0 \text{ in.}$$

$$\delta_{\text{over}} = 1.00 \text{ in.}$$

$$\text{Under-camber tolerance, } \delta_{\text{under}} = -0.50 * C_{\text{dp}} \leq -1.0 \text{ in.}$$

$$\delta_{\text{under}} = -1.72 \text{ in.}$$

Step 9: Account for over-camber

$$\text{Minimum haunch at midspan, } D_{2,\text{over}} = D_2 - \delta_{\text{over}} - \delta_{\text{CS}}$$

$$D_{2,\text{over}} = 4.08 \text{ in. (at edge of flange)}$$

OK, $D_{2,\text{over}} >$ minimum haunch thickness of 1.00 in. if girders over-camber by 20%

Step 10: Account for under-camber

$$\text{Maximum haunch at midspan, } D_{2,\text{under}} = D_2 - \delta_{\text{under}}$$

$$D_{2,\text{under}} = 8.08 \text{ in.}$$

$$\text{Weighted average haunch for DL, } D_{\text{avg,DL,under}} = \frac{(D_1 + 10 * D_{2,\text{under}} + D_3)}{12}$$

BDM Eq. 5-1

$$D_{\text{avg,DL,under}} = 7.24 \text{ in.}$$

$$\text{DL defl. (revised using } D_{\text{avg,DL,under}}), \Delta_{\text{DL,under}} = -1.58 \text{ in. (from software)}$$

$$\text{Residual camber} = C_{\text{dp}} + \delta_{\text{under}} + \Delta_{\text{DL,under}}$$

$$\text{Residual camber} = 0.13 \text{ in.}$$

OK, girder maintains positive camber if under-cambered by 50%

Note: Girder has been designed for all strength and service criteria using the following:

- $D_{2,\text{under}}$ as the haunch at midspan for composite section properties
- $D_{\text{avg,DL,under}}$ as the weighted average haunch thickness for dead load
- Girder design compressive strength, f'_c per BDM Section 5.3.1.2

CONCLUSION

A proposed haunch of 3 in. at CL of girder at supports passed all required checks. The haunch at supports was intentionally minimized to avoid an excessively thick haunch at midspan.

The example shows how a crest vertical curve adds to the haunch thickness at midspan and, in this case, results in a thicker estimated haunch at midspan than at supports. The haunch thickness at midspan is partially offset by the apparent sag effect of chording girders on a horizontally curved bridge deck.

Other geometric situations that will impact the haunch depth include flared girders and deck cross-slope transitions.

Case 2: Side-by-Side Box Girder Bridge

PROBLEM STATEMENT:

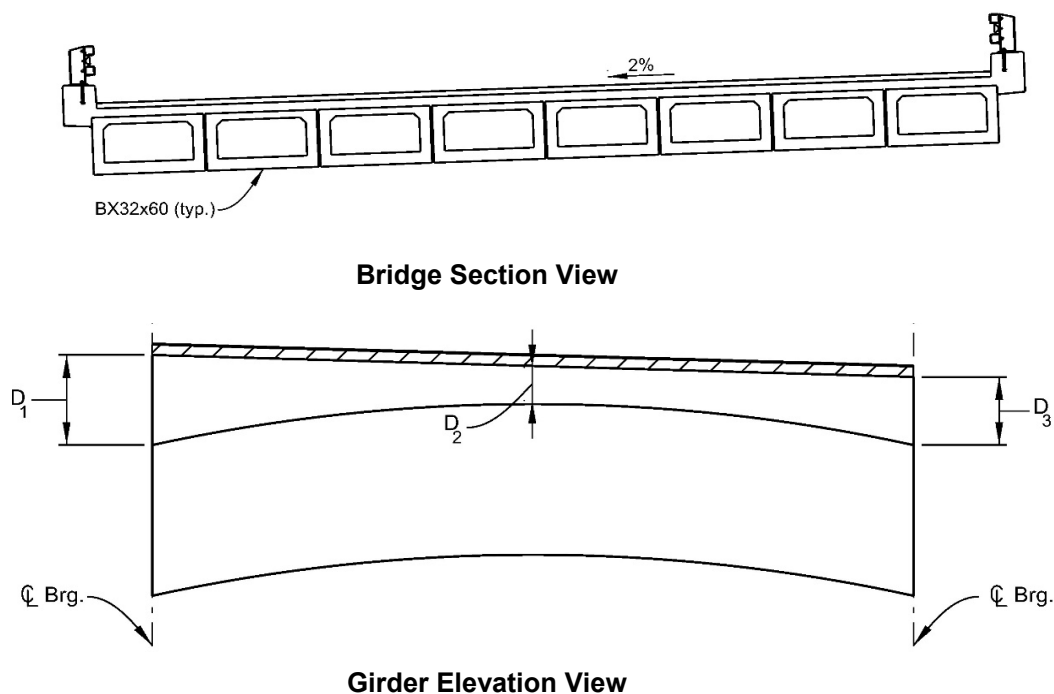
Case 2 illustrates how to set the deck thickness at supports for a side-by-side box girder bridge. The deck thickness at supports is set and verified with similar methodology used to set girder haunches, but without the need to accommodate partial depth deck panels. Per Section 9.5 of this BDM, a minimum deck thickness of 5 in. shall be maintained at all locations of side by side box girder bridges.

This example uses the option of specifying shims at the bearing seats in lieu of accounting for girder over-camber when checking minimum deck thickness, permissible per Section 5.5.2.1.G of this BDM. Also, the optional actual average values of girder strengths were used in determining the given values of predicted camber and dead load deflection, permissible per BDM Section 5.5.2.1.D.

The dead load deflections given in this example do not include an increase for long-term effects, permissible per BDM Section 5.5.2.1.E.

The bridge is on a vertical tangent with a constant deck cross-slope, and the girders are sloped to match. Therefore, the deck geometry does not impact the variable deck thickness.

Positive values indicate upward camber or deflection.



GIVENS:

Girder span length, L	=	100	ft.
Proposed deck thickness at CL abut., $D_1 = D_3$	=	8.00	in.
Assumed weighted average deck thickness for DL, $D_{avg,DL}$	=	5.54	in. (may require iteration)
Dead load deflection, Δ_{DL}	=	-1.68	in. (incl. superimposed DL)
Predicted girder camber at deck placement, C_{dp}	=	4.63	in. ($C_{dp} = P/S \text{ Camber} - \Delta_{\text{Girder Self Weight}}$)

CALCULATIONS:Step 1: Check estimated deck thickness at midspan

$$\text{Estimated deck thickness at midspan, } D_2 = \frac{D_1 + D_3}{2} - \Delta_{DL} - C_{dp}$$

$$D_2 = 5.05 \text{ in.}$$

OK, $D_2 >$ minimum deck thickness of 5 in.
Step 2: Verify assumed weighted average deck thickness for dead loads

$$\text{Actual weighted avg thickness for DL, } D_{\text{avg,DL}} = \frac{(D_1 + 10 * D_2 + D_3)}{12} \quad \text{BDM Eq. 5-1}$$

$$D_{\text{avg,DL}} = 5.54 \text{ in.}$$

OK, $D_{\text{avg,DL}}$ matches assumed weighted average thickness for dead loads

Note: Use D_2 as the deck thickness at midspan for the following items:

- Calculating Δ_{DL} reported on the girder sheet and used in setting deck elevations
- Calculating deck concrete quantity

$$\text{Weighted avg thickness for quantities, } D_{\text{avg,QTY}} = \frac{(D_1 + 2 * D_2 + D_3)}{4} \quad \text{BDM Eq. 5-2}$$

$$D_{\text{avg,QTY}} = 6.52 \text{ in.}$$

Step 3: Calculate camber tolerances per BDM 5.6.1.4 (50% over & 50% under for box girders)

$$\text{Over-camber tolerance, } \delta_{\text{over}} = 0.50 * C_{dp} \geq +1.0 \text{ in.}$$

$$\delta_{\text{over}} = 2.31 \text{ in.}$$

$$\text{Under-camber tolerance, } \delta_{\text{under}} = -0.50 * C_{dp} \leq -1.0 \text{ in.}$$

$$\delta_{\text{under}} = -2.31 \text{ in.}$$

Step 4: Account for over-camber

$$\text{Required Shim Height} = \delta_{\text{over}}$$

$$\text{Required Shim Height} = 2.31 \text{ in.}$$

Provide 2 5/16 in. shim stack and lower abutment seat elevations by same amount

Note: Add a plan note requiring that shims be removed only as necessary to maintain a 5 in. minimum deck thickness.

CALCULATIONS (Continued):Step 5: Account for under-camber

$$\text{Max. deck thickness at midspan, } D_{2,\text{under}} = D_2 - \delta_{\text{under}}$$

$$D_{2,\text{under}} = 7.36 \text{ in.}$$

$$\text{Weighted avg. thickness for DL, } D_{\text{avg,DL,under}} = \frac{(D_1 + 10 * D_{2,\text{under}} + D_3)}{12}$$

$$D_{\text{avg,DL,under}} = 7.47 \text{ in.}$$

$$\text{Deflection (revised using } D_{\text{avg,DL,under}}), \Delta_{\text{DL,under}} = -2.06 \text{ in. (from software)}$$

$$\text{Residual camber} = C_{\text{dp}} + \delta_{\text{under}} + \Delta_{\text{DL,under}}$$

$$\text{Residual camber} = 0.25 \text{ in.}$$

OK, girder maintains positive camber if under-cambered by 50%

Note: Girder has been designed for all strength and service criteria using the following:

- $D_{2,\text{under}}$ as the structural deck thickness at midspan
- $D_{\text{avg,DL,under}}$ as the weighted average deck thickness for dead load
- Girder design compressive strength, f'_c per BDM Section 5.3.1.2

CONCLUSION

A proposed deck thickness of 8 in. at the supports was determined to be acceptable. Using shims at the bearing seats as a strategy for addressing girder over-camber results in the following:

- Reduces specified deck thickness by 2.38 in
- Reduces dead load deflection by 0.57 in. for the girder sag check (under-camber case)
- Reduces deck concrete quantity by 32 cubic yards

Using the optional actual average girder strengths for camber and dead load deflections has the effect of reducing the predicted camber and dead load deflection magnitudes. The corresponding camber tolerances also decrease in magnitude as a result.

The combined strategies of using shims to account for over-camber and using the actual average girder strengths for predicted camber and dead load deflections may be advantageous when designing slender side-by-side box girders or slabs that would otherwise have difficulty meeting sag criteria.